THE ORIGIN OF OXYGEN ISOTOPE DISEQUILIBRIUM IN AN ALLENDE TYPE B1 CAI

N. Kawasaki[1], S. B. Simon[2], L. Grossman[2,3], N. Sakamoto[4] and H. Yurimoto[1,4,5]
[1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan (kawasaki@sci.planeta.isas.jaxa.jp), [2]Department of Geophysical Sciences, The University of Chicago, 5734 S. Ellis Ave., Chicago, Illinois 60637 USA., [3]The Enrico Fermi Institute, The University of Chicago, 5640 S. Ellis Ave., Chicago, Illinois 60637 USA., [4]Isotope Imaging Laboratory, Creative Research Institution, Hokkaido University, Sapporo 001-0021, Japan., [5]Department of Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan.

Introduction: Oxygen isotopes in the Solar System materials distribute with mass-independent isotope fractionation that maintains almost constant $^{17}O/^{18}O$ [e.g. 1, 2]. Coarse-grained Ca-Al-rich inclusions (CAIs) in meteorites, the oldest objects in the Solar System [3], exhibit unequilibrated O isotope distributions along the carbonaceous chondrite anhydrous mineral (CCAM) line, nearly slope-1 line on an O three-isotope diagram [4]. In typical fashion for the coarse-grained CAIs, the spinel and fassaite show ^{16}O-rich signatures, while the melilite and anorthite show ^{16}O-poor signatures [e.g. 4, 5]. However, the origin of the O isotope disequilibrium among the minerals in coarse-grained CAIs still remains controversial. We propose the O isotope disequilibrium in an Allende Type B1 CAI TS34 originates from an O isotope evolution of CAI melt during crystallization, based on a combined study of petrography and O isotope distributions. The O isotopic compositions of the minerals in TS34 were measured using a SIMS (secondary ion mass spectrometry) instrument (Cameca ims-1280HR) of Hokkaido University.

Results and Discussion: TS34 (Fig. 1) mainly consists of melilite, fassaite, and spinel in addition to minor anorthite, in igneous textures. Oxygen isotopic compositions of the minerals plot along the CCAM line. The spinel is uniformly ^{16}O-rich ($\Delta^{17}O = -22.7 \pm 1.7$‰, 2SD), while the melilite is uniformly ^{16}O-poor ($\Delta^{17}O = -2.8 \pm 1.8$‰). The fassaite crystals exhibit growth zoning overprinting poorly-developed sector zoning: they generally grow from Ti-rich to Ti-poor compositions (Fig. 2). The fassaite crystals show continuous variations in $\Delta^{17}O$ along the inferred directions of crystal growth, from ^{16}O-poor ($\Delta^{17}O \sim -3$‰) to ^{16}O-rich ($\Delta^{17}O \sim -23$‰) (Fig. 3), which covers a full range of O isotope variations of the minerals in TS34. The early crystallized ^{16}O-poor fassaite and the melilite are in O isotope equilibrium (Fig. 3). The O isotope variations in the fassaite likely correlate with the O isotope evolution of CAI melt during the fassaite crystallization, from ^{16}O-poor to ^{16}O-rich, which may have originated from O isotope exchange with surrounding ^{16}O-rich nebular gas. The ^{16}O-poor melilite could have equilibrated with the early crystallized fassaite, while the ^{16}O-rich spinel was a relict, at the melting and crystallization processes. On the other hand, anorthite exhibits O isotope variations ranging between $\Delta^{17}O \sim -2$‰ and −8‰, which could also have formed during the inferred melting and crystallization processes.

We additionally conducted high precision ^{26}Al–^{26}Mg systematics with SIMS [6] for TS34; an obtained ^{26}Al–^{26}Mg mineral isochron of the melilite and fassaite shows an initial value of $(^{26}Al/^{27}Al)_0 = (5.003 \pm 0.075) \times 10^{-5}$, which corresponds to a relative age of 0.05 ± 0.02 Myr from the canonical [7]. These data demonstrate that both ^{16}O-rich and ^{16}O-poor reservoirs had been existed in the solar nebula at least ~0.05 Myr after the birth of the Solar System.

References: [1] Clayton et al. (1973) *Science* **182**, 485−488. [2] Sakamoto et al. (2007) *Science* **317**, 231−233. [3] Connelly et al. (2012) *Science* **338**, 651−655. [4] Clayton et al. (1977) *Earth Planet. Sci. Lett.* **34**, 209−224. [5] Yurimoto et al. (1994) *Earth Planet. Sci. Lett.* **128**, 47−53. [6] Kawasaki et al. (2016) *Geochim. Cosmochim. Acta* doi: j.gca.2015.12.031. [7] Larsen et al. (2011) *Astrophys. J. Lett.* **735**, L37−L43.

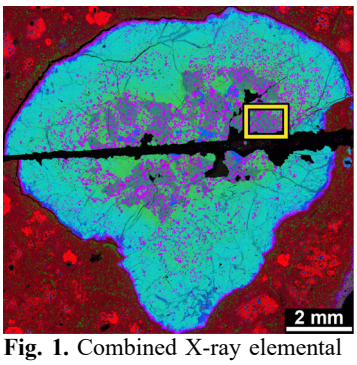

Fig. 1. Combined X-ray elemental map of an Allende Type B1 CAI TS34 with Mg (red), Ca (green), and Al (blue).

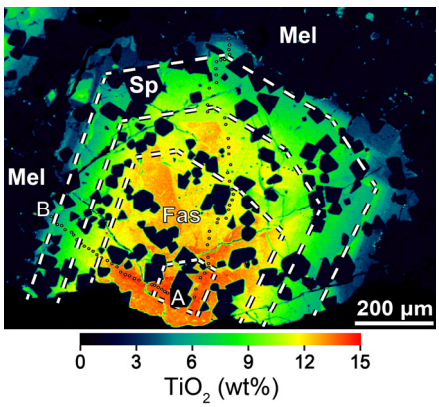

Fig. 2. Quantitative map of TiO_2 contents in a fassaite crystal of the rectangular area in Fig. 1. Dotted lines correspond to contours of crystal growth. Fas, fassaite; Mel, melilite; Sp, spinel.

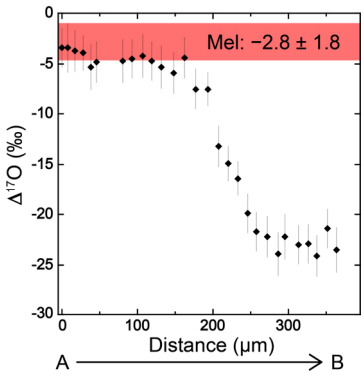

Fig. 3. Zoning of O isotopic composition ($\Delta^{17}O$) along the line A–B in Fig. 2. Allow corresponds to the direction of the crystal growth of fassaite. Errors are 2σ. The width of red shaded area covers ±2SD of $\Delta^{17}O$ for melilite.